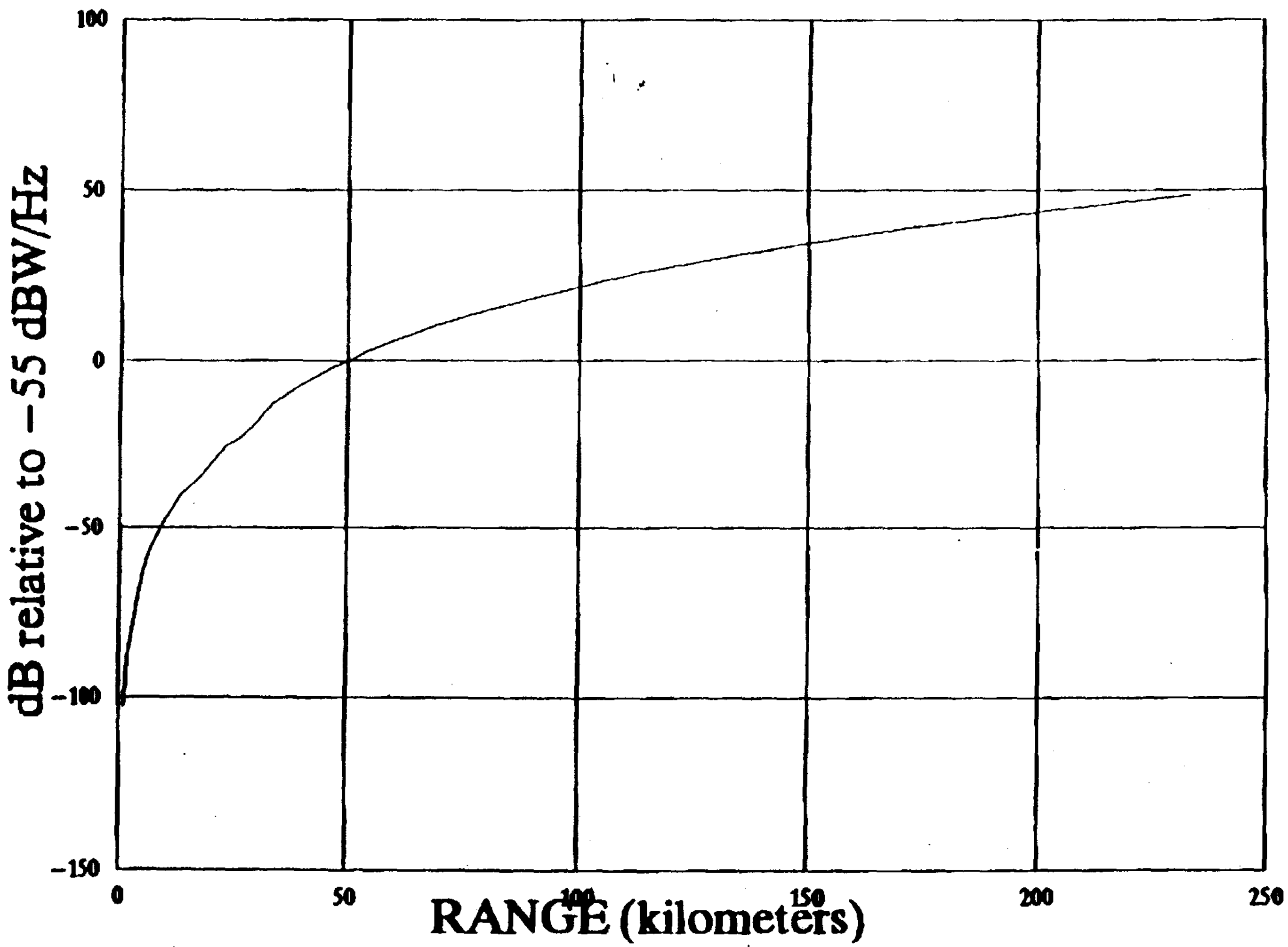

Figure 6-5. dB Relative to -55 dBW/Hz vs 0- to 250-km Range for 50-km Radius Sites (based on Okumura model for open areas)

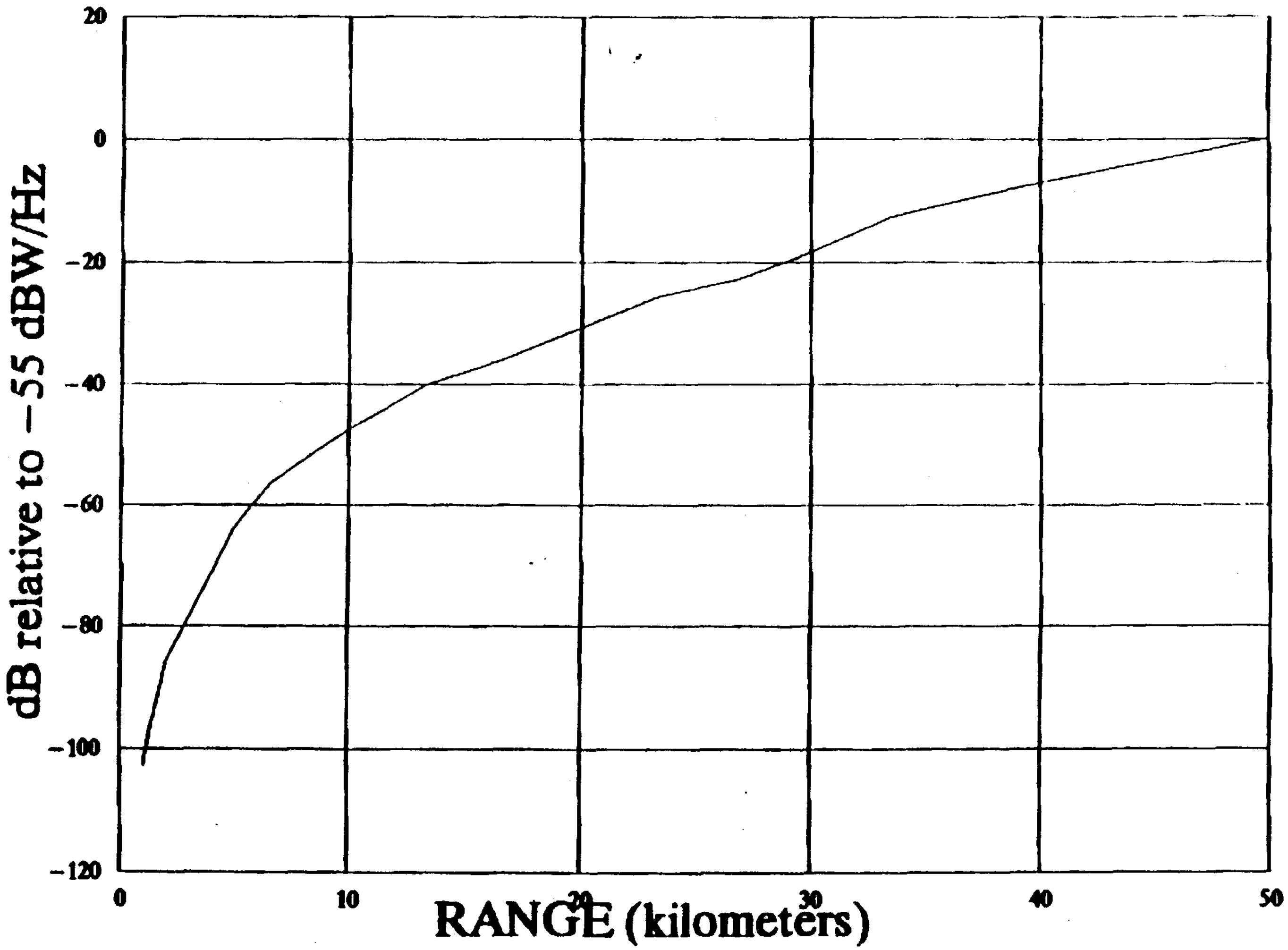

Figure 6-6. dB Relative to -55 dBW/Hz vs 0- to 50-km Range for 50-km Radius Site (based on Okumura model for open areas)

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necessary, and interference from terrestrial terminals could thus be prevented. However, out-of-band space-to-Earth emissions into the band 1,610.6 to 1,613.8 MHz from the adjoining band 1,613.8 to 1,626.5 MHz, and spurious emissions into the band 4,990 to 5,000 MHz from space-to-Earth emissions in the band 2,483.5 to 2,500 MHz, cannot be reduced from their minimum design values once the spacecraft has been placed in orbit. Therefore, all spacecraft to be launched must be designed and constructed to be capable of limiting such out-of-band and spurious emissions during radio astronomy observations to prevent harmful interference to all existing RA observatories and to those which may become operational during the lifetime of such spacecraft.

Prospective MSS/RDSS operators must establish that they can meet these requirements through analyses and testing. These analyses and test data shall be provided to the ESMU, well prior to launch, for use within the radio astronomy community, pursuant to a confidentiality agreement.

Considering all of the above, the IWG 2 comes to the following conclusions, and makes the following recommendations.

6.2.1 L-Band Downlinks

The spectral power flux-density (PFD) reaching the surface of the earth in the band 1,610.6 to 1,613.8 MHz from out-of-band emissions from all satellites in an MSS/RDSS system, in the band 1,613.8 to 1,626.5 MHz shall not exceed -238 dB(W/m^{2}Hz) during observations at the non-VLBA sites to be protected, and -198 dB(W/m^{2}Hz) during observations at the VLBA sites to be protected.

The IWG 2 believes that system operators can comply with this limit through a combination of high-pass filters in the satellite transmitter, and/or employment of a guard band between the lowest satellite channel to be used and the upper edge of the protected band, 1,613.8 MHz.

Prospective MSS/RDSS system operators should be required to include analyses, in their system applications to demonstrate that their systems will comply with this limit.

6.2.2 S-Band Downlinks

The spectral power flux-density (PFD) reaching the surface of the earth in the band 4,990 to 5,000 MHz from spurious emissions from all satellites in an MSS/RDSS system, in the band 2,483.5 to 2,500 MHz shall not exceed -241 dB (W/m^{2}Hz).

The IWG 2 believes that system operators can comply with this limit through a combination of suppression of second harmonics in satellite transmitters, and filtering of the output.

System operators should be required to include analyses, in their system applications to demonstrate that their systems will comply with this limit.

Annex A

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Summary of Meetings of Drafting Group A of IWG2

Meeting Date	Location
February 8, 1993	Rm 856, FCC
February 16, 1993	Rm 856, FCC
February 25, 1993	Rm 856, FCC
March 2, 1993	Rm 856, FCC
March 11, 1993	2000 L St, 2nd Flr
March 17, 1993	COMSAT, L'Enfant Plaza
March 23, 1993	Rm 856, FCC

Attachment B
to MSSAC-42.7 (Rev.5)

(also numbered as Doc. IWG2-74
(Rev.3) and MSSAC-42.5)

DRAFTING GROUP 2B OF

INFORMAL WORKING GROUP 2

TECHNICAL REPORT ON MSS/RDSS SHARING

WITH THE AERONAUTICAL RADIONAVIGATION

AND

RADIONAVIGATION-SATELLITE SERVICES

March 31, 1993

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DRAFTING GROUP 2B OF
INFORMAL WORKING GROUP 2

TECHNICAL REPORT ON MSS/RDSS SHARING WITH THE AERONAUTICAL RADIONAVIGATION AND RADIONAVIGATION-SATELLITE SERVICES

1. Introduction to GPS/GLONASS

1.1 Background

The GPS and GLONASS systems operate under the radionavigation-satellite (space-to-Earth) service allocation in the 1559-1610 MHz band and the GLONASS system also operates in the aeronautical radionavigation service allocation under Radio Regulation (RR) No. 732 in the 1610-1626.5 MHz band. Significant development of both GPS and GLONASS started in the 70s. The 1979 WARC allocated spectrum for GPS at the request of the USA. Initial satellites were launched in 1978 (GPS) and 1982 (GLONASS) for experimentation. While neither system has been declared operational, there are 4 block I (developmental), 9 block II & 9 block IIA GPS satellites in operation. GLONASS has 15 satellites in operation at this time. Both systems will have up to 24 satellites in operation at any given time when the systems are fully operational (1994 for GPS, 1995 for GLONASS). The 1992 WARC allocated spectrum to the mobile-satellite service in the 1610-1626.5 MHz band, which overlaps the spectrum used by GLONASS and is adjacent to the band used by GPS.The 1992 WARC allocated spectrum for mobile-satellite in the 1610-1626.5 MHz band which GLONASS currently uses a portion from 1610-1616 MHz.

1.2 Basic System Description

GPS is a space-based positioning, velocity and time system that has three major segments: space, control and user. The GPS space segment, when fully operational, will be composed of 21 satellites (plus 3 operational spares) in six orbital planes. The satellites will operate in circular 20,200 km (10,900 nm) orbits at an inclination angle of 55 degrees and with a 12-hour period. Each satellite will transmit on two right-hand circularly polarized frequencies L1 (1575.42 ± 1.023 MHz for C/A code) and L2 (1227.60 MHz). L1 will carry a precise (P) signal (provides the Precise Positioning Service (PPS) of ±10.23 MHz which is not available for public use) and a coarse/acquisition (C/A) signal which is used for the Standard Positioning Service (SPS). L2 will carry only a P signal of ±10.23 MHz. Superimposed on these signals will be navigation and system data including satellite ephemeris, atmospheric propagation correction data, and satellite clock bias information. The minimum signal level specified into a 3 dB linearly polarized user receiver antenna[1] located near the

[1]This is equivalent to using a 0 dB right-hand circularly polarized antenna and measuring at the antenna connector.

ground with a 5 degree elevation angle is -160 dBW for SPS and -163 dBW for PPS. Technical system details are in the GPS Interface Control Document, ICD-GPS-200 (IRN-200B-PR-001, 1 July 1992) available to the public through the U.S. Coast Guard.

The GLONASS satellite subsystem will include 24 satellites evenly distributed in three orbit planes, eight satellites each plane. Orbit parameters include an altitude of 19,100 km with a period of 11 hours and 15 minutes. The planned rate of replenishment launch is one launch per 7 months of three satellites. The GLONASS functions are similar to GPS except that GPS uses one frequency for all satellites and GLONASS uses 24 frequencies (1602.5625 MHz for the first frequency with each center frequency 0.5625 MHz spacing above for L1). Each satellite has a bandwidth of ±0.511 MHz for C/A signal and ±5.11 MHz[2] for precision signal which is not available for public use. The minimum signal level specified into a 3 dB linearly polarized user receiver antenna[3] located near the ground with a 5 degree elevation angle is -161 dBW for SPS. Technical system details are in the GLONASS Interface Control Document, (RTCA 518-91/SC159-317, MSSAC-27).

The control segments for GPS and GLONASS, each includes a number of monitor stations and ground antennas located throughout the world (GLONASS stations are not as distributed thought the world). The GPS monitor stations use a receiver to passively track all satellites in view and thus accumulate ranging data from the satellite signals. GLONASS satellites are also tracked optically. The information from the monitor stations are processed at the master control station (MCS) to determine satellite orbits and to update the navigation message of each satellite. This updated information is transmitted to the satellites via ground antennas, which can also be used for transmitting and receiving satellite control information.

The user segment will consist of antennas and receiver-processors that provide positioning, velocity and precise timing to the user. The GPS/GLONASS receiver automatically selects appropriate signals from four of the satellites best in view based on optimum satellite-to-user geometry. It then solves time-of-arrival difference quantities to obtain distance between user and satellites. This information establishes the user position with respect to the satellite system. A time correction factor then relates the satellite system to earth coordinates. User equipment measures four independent pseudo-ranges and range rates and translates these to three-dimensional position, velocity and system time.

There is a 98 percent probability that at least 21 satellites of the 24-satellite GPS constellation will be operational simultaneously. The probability for GLONASS is unknown but the satellite design life of GLONASS is 3 years (2.87 for second half on 1992, new modification 3.14 projected) with a program to upgrade to 5 years while GPS satellites have a design life of 7.5 years. GPS satellites are launched one at a time and GLONASS satellites can be launched three at a time.

---

[2]This is only applies to GLONASS-M

[3]This is equivalent to using a 0 dB right-hand circularly polarized antenna and measuring at the antenna connector.

1.3 Operational Applications

RTCA, Inc. has studied issues related to implementation of the Global Navigation Satellite System (GNSS), which includes GPS and GLONASS, and produced a report entitled "RTCA Task Force Report on the Global Navigation Satellite System (GNSS) Transition and Implementation Strategy." This report was based on a solid consensus that the aviation user community wants, needs and is ready to implement GNSS-based operations. This report was produced by more than 200 interested aviation individuals representing the full cross-section of the aviation community. The report includes 116 recommendations. Some of these related to operational applications are provided below.

> "The FAA should base GNSS initial operational implementation on the use of the U.S. Global Positioning System national resource and appropriate augmentations. The early system configuration should be expanded to accommodate the Russian GLONASS and other satellites and augmentations as they become available."
>
> "The goals of the aviation industry are twofold with respect to GNSS. First is to immediately derive all possible advantages from GNSS. Second is to replace all existing navigation sensors with equipment that utilizes GNSS, wherever GNSS performance is superior and cost-effective or can enable application that are not feasible today using other sensors."
>
> "The new GNSS-based system should provide, as a minimum, en route, oceanic, terminal and non-precision approach navigation service with an accuracy of 100 meters."
>
> "The industry and the FAA should develop carrier phase differential technology, which is capable of supporting sub-meter position determination accuracies, to support approaches with more support minima than those of Special Category I.[4]

The task force report indicates that supplemental navigation can be used now and that precision approaches could start in 1994 with GNSS-based automatic landing and takeoff using carrier phase differential being implemented by 1997. This report addresses all phases of operation including surface operations at airports. The report indicates that from the standpoint of the space and ground control segments, GNSS sole means of navigation should be available by 1995. The FAA has approved Technical Standing Order TSO-C129 authorizing the use of airborne GPS equipment for supplemental navigation as a first step in GNSS implementation.

The Air Transport Association (ATA) member airlines are pursuing the use of GNSS signals for en route and terminal operations, including complex approach and

[4]Special Category I Approach is a specially authorized differential global navigation satellite system (DGNSS) Instrument Approach using a SGNSS Instrument Approach System satisfying a specific required navigation performance (RNP) that allows operations to MLS/ILS Category I minima, with differential GNSS used to provide navigation guidance.

departure paths and profiles. The airlines expect that GNSS position and time determination capability and performance will beneficially improve safety and precision of navigation in all phases of flight. The following operational requirements/goals were developed by the ATA:

> "GNSS position shall be certified for primary and sole means navigation applications in en route, transitional and terminal area airspace.
> GNSS will be used for precision advanced arrival and departure routing without use of ground aids.
> GNSS will be used for CAT I, precision approach without use of ground aids.
> GNSS is expected to ultimately be capable of CAT II/III approaches.
> GNSS precision position determination capability shall be used for aircraft ground movement guidance/surveillance.
> GNSS shall be used for Automatic Dependent Surveillance (ADS). Separation standards and ATC procedures shall make full use of GNSS accuracy.
> GNSS will utilize information from both the GPS and when available, the GLONASS satellite constellations."

1.4 Existing Regulatory Protection

MSS/RDSS and GPS/GLONASS operations in adjacent bands are mutually protected by RR No. 343 (Article 6), which requires that frequency assignments be sufficiently removed from the band edge to prevent adjacent-band interference at harmful levels. MSS and aeronautical radionavigation (e.g. GLONASS) have international co-primary allocations in the band 1610-1626.5 MHz. GLONASS operates in the band 1610-1616 MHz pursuant to Radio Regulation 732 as a result of successful Article 14 coordination. With respect to the aeronautical radionavigation service, Radio Regulation Numbers 731E and 731F are applicable.

Radio Regulation 731E provides that the use of the 1610-1626.5 MHz by RDSS and MSS is subject to the coordination and notification procedures of Resolution 46 adopted at WARC-92. Such coordinations may be invoked under Section II of Resolution 46 by any administration which believes that "interference may be caused to assignments of its existing or planned satellite networks or to assignments to its existing or planned terrestrial radiocommunications stations."

In addition, RR 731E provides that RDSS and MSS mobile earth stations shall not produce an EIRP density in excess of -15 dB(W/4kHz) in the part of the band used by systems operating in accordance with the provisions of No. 732 (e.g., GLONASS), or an EIRP density of -3 dB(W/4kHz) in the balance of the band, unless agreed by the affected administrations. RR 731E also states that stations of the mobile-satellite service shall not cause harmful interference to, or claim protection from, stations in the aeronautical navigation service, stations operating in accordance with the provisions of No. 732 (e.g., GLONASS) and stations in the fixed service operating in accordance with the provisions of No. 730.

RF 731F provides that use of the band 1613.8-1626.5 MHz by MSS in the space-to-Earth direction also is subject to the procedures of Resolution 46.

Thus, pursuant to these international regulatory provisions, the GLONASS administration will have the opportunity to engage in coordination with RDSS/MSS systems proposing to use the 1610-1626.5 MHz band in the Earth-to-space direction and with RDSS/MSS systems proposing to use the 1613.8-1626.5 MHz bands in the space-to-Earth direction. In addition, any administration using the GLONASS system also will have the opportunity to coordinate with RDSS/MSS systems proposing to use the bands, if it believes that harmful interference may occur to the GLONASS terminals operating within its territory.

RDSS/MSS systems can exceed the EIRP density limits specified in RR 731E with the agreement of affected administrations. Radio Regulations Nos. 2541 and 2548A establish EIRP density limits for the relevant frequency band of +40 dBW/4kHz (soft limit, per RR. No. 2546) and -3dBW/4kHz (hard limit).

In developing recommendations to the FCC with regard to protection of GLONASS, the Informal Working Group 2 (IWG2) has taken into consideration the existing Radio Regulations, the stated requirements for use of GLONASS receivers as a component of the GNSS as well as the requirements of U.S.-proposed RDSS/MSS systems to use the 1610-1626.5 MHz frequency band.

1.5 Future Changes & Enhancements

The Russian Administration recently submitted advanced publication information with the IFRB describing certain characteristics of the GLONASS-M system. As described, the proposed GLONASS-M system would use an additional modulation (or "P Code") which adds a signal bandwidth to each GLONASS frequency of +/- 5.11 MHz. This additional modulation would extend the upper range of the GLONASS transmissions to 1620.6 MHz.

Approximately 40 countries, including the United States, submitted comments/objections to the IFRB on the GLONASS-M system in response to the Russian advanced publication. GLONASS-M must be coordinated internationally under Article 14 in order to obtain recognition under the international Radio Regulations. The GLONASS-M system would further increase the interference to Radio Astronomy Service (1610.6-1613.8 MHz band) already affected by GLONASS. (see IWG2-Drafting Group 2A Report)

Section 3.1 proposes changes to the GLONASS/GLONASS-M frequency assignments in order to eliminate or reduce the interference caused to Radio Astronomy and enhance sharing with MSS/RDSS.

The P Code signal from GLONASS-M is not envisioned by the FAA or ICAO to be part of the GNSS system and is believed to be accessible by only the Russian military establishment. In light of this and the Article 14 coordination required for GLONASS-M, IWG2 agreed to assume that reception of the GLONASS-M P Code signal need not be protected, and to recommend that the United States should take a position consistent with this assumption during its Article 14 coordination. Because the P Code signal has been observed from the present GLONASS system, however, it was agreed that the P Code signal should be considered as a source of interference to MSS/RDSS systems. IWG2 recognized that the GLONASS system was coordinated according to Article 14 when it was advance published by the IFRB (circa 1983).

Moreover, it was agreed that the Russians should be urged to install filters that limit the emission power outside the fundamental C/A emission to the maximum extent practical in order to reduce interference to Radio Astronomy and MSS/RDSS systems (see Section 3.1.).

2. Mutual Interference Considerations Between GLONASS and MSS/RDSS Systems

2.1 Potential MSS/RDSS Handheld Interference into GLONASS Measurements and Analysis

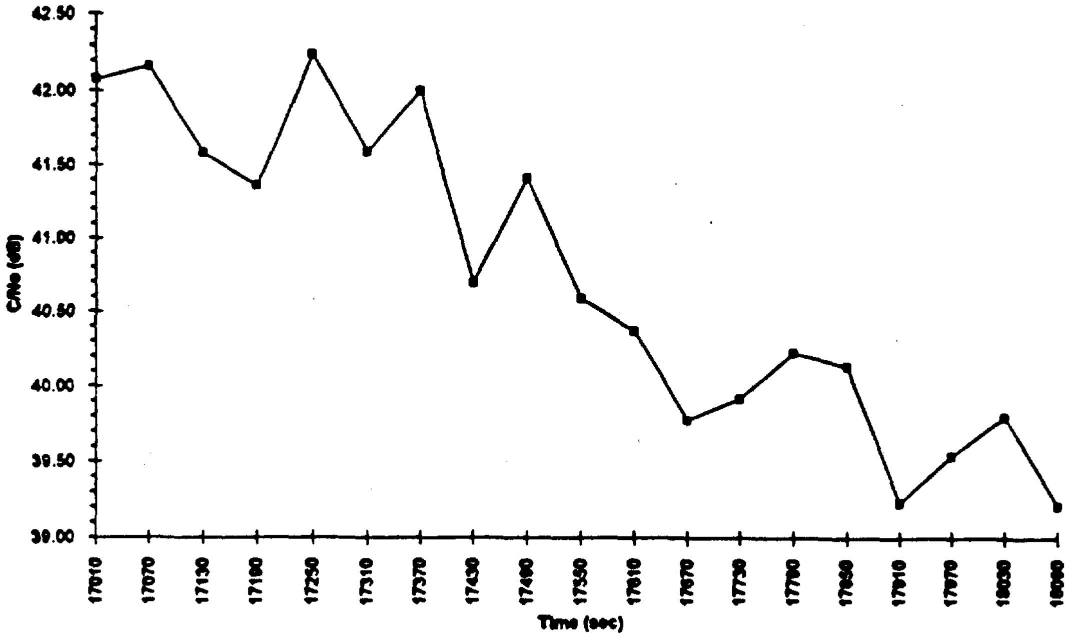
2.1.1 GLONASS Interference Immunity Measurements

COMSAT's interest in the possible future use of the 1610-1626.5 MHz band by INMARSAT, for Project 21, prompted them to contact 3S-Navigation, Laguna Hills, California, to investigate the potential immunity or susceptibility of GLONASS aeronautical navigation receivers (used on commercial aircraft) to in-band interference from the uplink transmissions of LEO or GEO mobile (hand-held) terminals.

Through the cooperation and resources of the two companies several 3S-Navigation prototype GPS/GLONASS R-100 receivers and two Russian-made ASN-16 GLONASS receivers were made available for interference tests for a limited time at COMSAT Laboratories and later at 3S-Navigation's technical facilities, in California--during September and October, 1992.

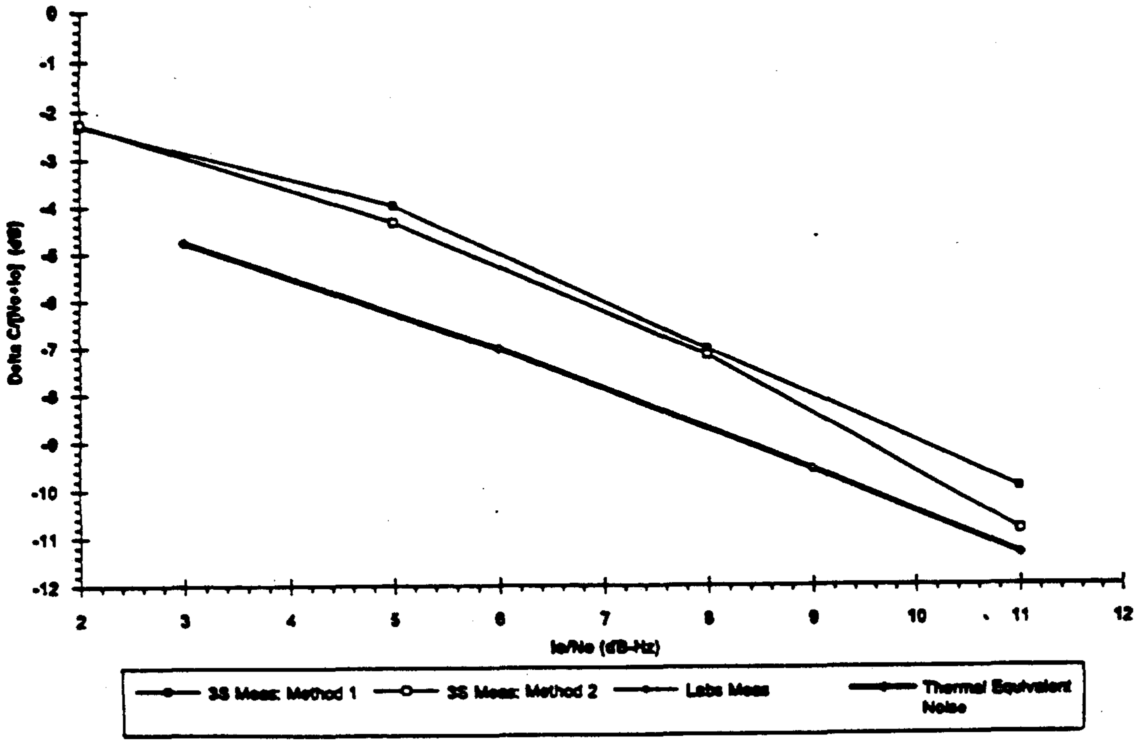
In both the tests at COMSAT Labs and at 3S-Navigation, "live" signals from actual GLONASS satellites were used, although the absolute levels of GLONASS signals were not measured. However, the R-100 receiver permitted accurate measurement of the receiver carrier-to-noise(thermal), C/No, or carrier-to-(noise+interference), C/(No+Io). Figure 2.1.1-1, gives an actual plot of C/No as a function of time, in the absence of interference, using the calibrated 3S-Navigation R-100 prototype receiver. Unfortunately, it was not possible to calibrate the Russian-made ASN-16 GLONASS receivers, due to their design and packaging for Russian military applications--so no test data is shown for these receivers. The variation in signal level with time is due to the joint effect of the GLONASS satellite change in elevation angle, as seen from the test site, as well as differences in gain versus angle of arrival for both satellite and GLONASS receiver antennas.

Figure 2.1.1-1
GLONASS C/No as a Function of Time in the Absence of Interference



Both CW and simulated spread-spectrum signals were injected into the line between the GLONASS receiver and its receiving antenna. The detailed test set-up is beyond the scope of the this report. However, the results of interest to IWG-2 are shown in Figure 2.1.1-2. In this plot, the effect of the interference on GLONASS receiver performance is shown as a change or delta in the C/(No+Io), for increasing levels of interference. The interference noise density levels are referenced to the receiver's internal thermal noise density, No. Thus, the interference level is expressed as Io/No. In this test, a 300 BPSK, random modulated (1/0) bit stream was used to represent an interfering, spread spectrum 600 KHz transmission, centered, co-channel with the particular GLONASS channel(s) being tracked on the R-100.

Figure 2.1.1-2
Changes in C/(No+Io) due to Co-Channel Interference (600 KHz)



The plot shows a decrease in C/(No+Io) for increasing Io/No, basically at a slope of slightly less than a dB for dB. The plot in Figure 2.1.1-2 also shows the effect of thermal equivalent Gaussian noise, in a bold line, for comparison. As seen, the effect of thermal equivalent noise at a given Io/No, is somewhat worse than the 600 KHz spread spectrum interference and the change in C/(No+Io) with Io/No follows approximately a dB for dB slope.

Other test data indicates that the front-end bandwidth of the GLONASS receiver was about 600 to 700 KHz, yielding a receiver sensitivity consistent with the C/No measurements. Furthermore, during these tests it was found that none of the navigation outputs from the receiver, as displayed on the attached computer screen (latitude/longitude/altitude, VMG) was affected by the injected interference until the receiver lost track or synchronization. For the prototype R-100 receiver, track was lost or significant bit errors were observed typically when the C/(No+Io) value had dropped to levels below about 28 to 30 dB-Hz. Integrated C/No-thermal levels during the tests typically ran between 39.5 to 42.5 dB-Hz. Thus, the useful dynamic range of the

GLONASS receiver with co-channel spread-spectrum interference (over the bandwidth of the receiver) is approximately 12 to 15 dB. However, according to 3S-Navigation, the manufacturer of the receiver tested, the R-100 is a prototype not specifically designed to reject in-band interference in an optimal way. The Russian made ASN-16, while not precisely calibrated, appeared to have at least 10 dB higher immunity than the R-100 (based on the point where synchronization was lost during interference tests).

2.1.2 Interference Analysis Based on Established and Proposed GNSS Characteristics

This analysis is based on established and proposed GNSS requirements in RTCA documents, ARINC Characteristic 743A and other related documents. The analysis addresses requirements placed on the equipment for interference rejection and then addresses losses and gains to determine the maximum interference EIRP that could be allowed for equipment with these characteristic. Results of tests are also used only to the extent to show that interference to this type of equipment can occur at very low levels and that there is not a significant (more than 10 dB) difference between narrow band (less than 600 Hz) or wide band (1 MHz) interference.

2.1.2.1 Avionics Protection Criteria.

The Airlines Electronic Engineering Committee (AEEC) has produced ARINC Characteristic 743A which describes the form, fit and function characteristics of a Global Positioning System (GPS) and GLONASS avionics sensor unit. This characteristic is currently under review for revision in several areas including interference rejection where the current interference-to-carrier ratio is 13 dB. RTCA Minimum Operational Performance Standards (MOPS) for GPS will have similar requirements. Shown below are the current AEEC proposed requirements for in-band and out-of-band interference rejection.

2.1.2.1.1 In-Band Rejection

The proposed new wording for in-band signal rejection states:

"After steady state navigation has been established, the sensor unit shall acquire and maintain code and carrier lock of a GPS signal at -136 dBm in the presence of an in-band interfering signal in the frequency range of 1575.42 ±2 MHz that is not more than the following levels as a function of interfering signal bandwidth BW_i:

$0 \leq BW_i \leq 600$ Hz:	-126 dBm
$600 < BW_i \leq 1$ kHz:	-121 dBm
1 kHz $< BW_i \leq 10$ kHz:	$-121 + 6 \cdot \log_{10}(BW_i/1000)$ dBm
10 kHz $< BW_i$:	-115 dBm

After steady state navigation has been established, the sensor unit shall acquire and maintain code and carrier lock of a GLONASS signal at -137 dBm in the presence of an in-band interfering signal in the frequency range of 1602-1616 MHz that is not more than the following levels as a function of interfering signal bandwidth BW_i:

$0 \leq BW_i \leq 600$ Hz: -121 dBm

600 < BW_i: -116 dBm

All values are measured at the input to the sensor unit."

2.1.2.1.2 Out-of-Band Rejection

The proposed new wording for out-of-band signal rejection states:

"The sensor shall meet its performance requirements when multiple carriers exists in the SATCOM band (1626.5 - 1660.5 MHz) that can generate intermodulation products of 7th order or higher in the GPS/GLONASS band (1559 - 1617 MHz).

The signal rejection envelope shown in Attachment 5-2 takes into account a required installation of 40 dB between the SATCOM antenna and the GPS/GLONASS antenna, in accordance with paragraph 5.5.2.

Attachment 5-2 (alternate configuration), ARINC Characteristic 743A, will show out-of-band curve with rejection points at:

1.525 GHz: -12 dBm

1.56 GHz: -50 dBm

1.57 GHz to 1.617 GHz: value depends on bandwidth and frequency as provided in 2.1 above for in-band rejection.

1.6265 GHz: -5 dBm"

2.1.2.2 Radionavigation Satellite Signal Levels and Airborne Antennas

GPS: The lowest GPS signal by specification (ICD-GPS-200) is -130 dBm (-160 dBW).

GLONASS: The lowest GLONASS signal by specification (ICD-GLONASS) is -131 dBm (-161 dBW).

Antenna Considerations: The following chart shows the minimum antenna gain requirements (ARINC 743A):

Elevation Angle	Minimum Gain[5]
>15°	-2 dBic
10°	-3 dBic
5°	-4.5 dBic
0°	-7.5 to -5.0 dBic

Note that there is no maximum gain requirement. Because the desired signal can be received with no problem down to 5 degrees antenna elevation angle where there is at least -4.5 dBic of gain and the interference signal can be received at other angles especially when the aircraft is in a turn, at elevation or climbing, the interference signal could experience a gain of up to at least +2.5 dBic. This results in up to 7 dB gain difference between the desired signal and the interference signal. Satellites tracked at lower antenna elevation angles could result in a larger difference. Coupling of the interfering signal to the antenna could experience an antenna gain as high 2.5 dB in the direction of the interference while the intended satellite signal could experience an antenna gain as low as -4.5 dB. This creates an additional 7 dB

[5] Typical antenna patterns show maximum gain values as high as 2.0 dBic depending on the elevation angle.

problem but could be compensated by the propagation loss due to the distance from the interference source. ARINC Characteristic 743A assumes a signal loss of 4.5 through the antenna at an elevation angle of 5 degrees. Only the minimum gain is specified. It is not clear what the maximum antenna gain would be but the maximum antenna gain is not expected to be very much above 2.5 dB.

One could state that an aircraft in level flight with a top mounted antenna provides a certain amount of additional isolation from ground transmissions but this is not the case because many aircraft do not fly level (some fly with 4° pitch or more) and in the terminal area they may have a pitch of up to +20°/-5° and roll of +25°/-25°.

2.1.2.3 Test Measurement Results

Flight tests using a race track pattern (10 km by 33km, 8000 ft high) were conducted (Owen) in the United Kingdom and demonstrated that interference power levels (2 MHz FM noise source) above -100 dBm (-130 dBW) (based on GPS signal of -157 dBW) caused significant degradation in the performance including complete loss of operation of the a GPS receiver under test. A variety of radiation sources were used in ground tests to confirm results such as CW, FM modulated carrier, AM and FM noise. No significant differences were observed between the effects of CW and narrow band noise up to a bandwidth of 1 MHz. Levels below -130 dBW can cause degradation of performance.

These test measurements confirm that low signal levels of -100 dBm (-130 dBW) or more will cause harmful interference with GPS. Similar interference to GLONASS can be expected. Harmful interference could occur at even lower levels because of the assumptions used. Since the interference level to avionics is stated and is tested to a given value, this becomes the starting point for interference analysis because the manufacturer does not guarantee interference protection for higher levels. Radio Regulation 953 indicates a need for special measures to protect a safety service. CCIR Report 927-2 discusses a need for an adequate margin for protection.

2.1.2.4 Analysis

Below is an analysis chart which shows how a specification on maximum effective isotopically radiated power (EIRP) for mobile earth stations could be developed using certain assumptions. These assumptions are based on current discussions related to the ability of a manufacturer to certify that their equipment tolerates a certain level of interference. ARINC Characteristic 743A, alternate configuration, is used to determine the minimum signal at the receiver. For analysis, the minimum signal in space for GLONASS is assumed to be -131 dBm with a 4.5 dB loss in antenna gain at 5 degrees elevation angle and a 1.5 dB loss in the cable to the receiver. This results in a satellite signal level of -137 dBm at the receiver. It is hoped that this chart will serve as a basis for future discussions on interference protection criteria for radionavigation satellite receivers. The result is that the EIRP from a mobile earth station 100 meters from an aircraft should be less than -43.5 dBm (-73.5 dBW) in order to ensure no harmful interference to the GLONASS receiver.

The only question left is how far will the interference source or transmitter sharing the band be from the aircraft and what extra margin is needed to protect the safety service so that the probability of interference is less than 1 in 10^9 required for precision landing. A distance of 100 meters appears reasonable as a worst case for an aircraft landing. Since a detailed analysis has not been done on the probability of interference causing a problem, an extra margin of 3 dB will be used to ensure an adequate protection margin.

The above analysis is based on proposed changes to ARINC Characteristic 743A where 21 dB interference-to-carrier is used. This characteristic is used by airlines for avionic installations but is not normally used by other types of general aviation aircraft. Some general aviation type aircraft manufactures have indicated that they would like to see a maximum interference-to-carrier value of about 16 dB used especially in cases where multi-channel satellite communication equipment is not installed on the same aircraft. Using the 16 dB criteria results in a maximum interference EIRP of -49.5 dBm for GPS and -48.5 dBm for GLONASS. For discrete spurious or CW interference to GPS a maximum of 10 dB interference-to-carrier is required. The table 2.1.2-1 below shows the analysis for an interference source 100 meters from the aircraft antenna.

Table 2.1.2-1 Development of GLONASS Interference Criteria (100m)

	Carriers	Interference	Comment
Minimum Signal Level at Receiver Input	-137 dBm	-121 dBm	Interference-to-Carrier Ratio Certified by Manufactures
Maximum Cable Loss to Receiver	-1.5 dB	-1.5 dB	Cable between Antenna and Receiver
Signal Level at Antenna	-135.5 dB	-119.5 dB	
Antenna Gain[6]	-4.5 dBic	2.5 dBic	Difference Due to Different Angles
Signal at Antenna	-131 dBm	-122 dBm	Signal in Free Space
Maximum Allowable Interference at Antenna		-122 dBm	
Nominal Path Loss Between Antenna and Interference Source 100 m away		-76.5 dB	20*Log(1602) + 20*Log (100) - 27.56 = 76.5 dB
EIRP of Interference Source (Single Entry value)		-45.5 dBm	
Extra Margin of Protection		-3 dB	Extra Margin to Ensure Protection Against Interference from Unknown Factors
Maximum EIRP Allowed for No Harmful Interference (including 3 dB Extra Margin of Protection)		-48.5 dBm (-78.5 dBW)	EIRP Density Limit per 1 MHz if the interference source is 100m away

[6]Typical antenna patterns show maximum gain values as high as 2.0 dBic depending on the elevation angle.

An additional analysis in Table 2.1.2-2 below shows the Maximum interference EIRP that could be allowed if the aircraft was at 10,000 meters. The interference source is not assumed to be directly under the aircraft and thus no shielding from the aircraft is assumed and a slant range of 12,000 meters is used. This assumption has, in principle, been confirmed in flight tests at 8000 ft with a GPS reciever. Coupling through the GNSS antenna by the interference source is assumed to be at a net gain of -4dBic.

Table 2.1.2-2 Development of GLONASS Interference Criteria (12,000 m)

	Carriers	Interference	Comment
Minimum Signal Level at Receiver Input	-137 dBm	-121 dBm	Interference-to-Carrier Ratio Certified by Manufactures
Maximum Cable Loss to Receiver	-1.5 dB	-1.5 dB	Cable between Antenna and Receiver
Signal Level at Antenna	-135.5 dB	-119.5 dB	
Antenna Gain	-4.5 dBic	-4.0 dBic	Difference Due to Different Angles
Signal at Antenna	-131 dBm	-115.5 dBm	Signal in Free Space
Maximum Allowable Interference at Antenna		-115.5 dBm	
Nominal Path Loss Between Antenna and Interference Source 12,000 m away		-118.1 dB	20*Log(1602) + 20*Log (12000) - 27.56 = -118.1 dB
EIRP of Interference Source (Single Entry Value)		2.6 dBm	
Extra Margin of Protection		-3.0 dB	Extra Margin to Ensure Protection Against Interference from Unknown Factors
Maximum EIRP Allowed for No Harmful Interference (Including 3 dB Extra Margin of Protection)		-0.4 dBm (-30.4 dBW)	EIRP Density Limit per 1 MHz if the interference source is 12,000m away

In summary, the maximum interference EIRP/1 MHz for surface, departure and landing operations should be restricted to -78.5 dBW (assumes interference source is no more than 100 m away). For the example of an aircraft at an altitude of 10,000 meters (12,000 m minimum slant range from interference source) the maximum interference EIRP density could reach levels as high as -30.4 dBW/1 MHz without causing unacceptable interference.

2.1.2.5 Requirements for Limits on Emissions From MSS in the 1559-1610 MHz Band

Operation of MSS/RDSS in the 1610-1626.5 MHz should not impact services in adjacent bands. GPS and GLONASS operations in the 1559-1610 MHz band are of particular concern. The analysis shown in this section for co-frequency GLONASS interference criteria at 100 m would also apply for the 1559-1610 MHz band emissions. In the case of GPS, similar analysis can be accomplished using 10 dB interference-to-carrier instead of 16 dB for CW or emissions with a bandwidth of 0 to 600 Hz. This results in a requirement to limit emissions to -83 dBW/600 Hz (in the case of CW interference). GPS can be protected from emissions of greater bandwidth (above 600 Hz) using an interference-to-carrier value of 16 dB. This results in a requirement of emission limit of -77.5 dBW/2 MHz.

MSS applicants stated that the protection limit specified by aviation for GLONASS in the 1602-1610 MHz band would be inconsistent with operating MESs in the 1610-1616 MHz up to -15 dBW/4kHz e.i.r.p limit. To meet the proposed GLONASS out-of-band emission protection level sought by aviation, when utilizing the -15 dBW/4kHz limit, would require the MES out-of-band emission density to be 79 dB below the in-band emission density. For those MES operating just above 1610 MHz band limit, this emission limitation would be greater than 50 dB more stringent than the present emission limitation specification. The present FCC Emission Limitation as defined in FCC Part 25.202(f) states that the first tier of emissions outside the authorized bandwidth be 25 dB down in any 4 kHz bandwidth. Subsequent steps or tiers call for suppression levels of 36 dB and nominally 43 dB down. The width of a step or tier is a function of the authorized bandwidth.

2.1.3 Potential MSS/RDSS Handheld Terminal Interference into GLONASS

2.1.3.1 MSS/RDSS CDMA Systems

The following paragraphs describe potential interference from CDMA MES handheld terminals into GLONASS receivers. Analysis is provided for nominal a set of en route aircraft conditions. A discussion of GNSS system availability is also provided.

2.1.3.1.1 Relevant CDMA System Characteristics

The CDMA system MES uplinks will operate over the 1610 to 1626.5 MHz with channel bandwidths wider than 1 MHz. The nominal handheld MES EIRP density varies among the system users; however, a value of -25 dBW/4 kHz will be used in the following analysis. This level is 10 dB below the -15 dBW/4 kHz level as specified in RR731E. Based upon user traffic estimates from IWG1, the composite number of simultaneous CDMA users within the continental United States is on the order of 12,550 MES during peak loading hours after several years of operation. This would provide an average density of approximately 0.004 CDMA users per square mile during the peak loading hours. At other times of the day, the average user density would be lower.

2.1.3.1.2 CDMA MSS and GLONASS Sharing Analysis for High Altitude En Route Navigation

The following is a limited-case analysis of the possible interference effects on airborne GLONASS receivers from a CDMA MES terminal on the ground. The specific assumptions were:

- the aircraft is at 10,000 m
- MES within a 45° cone of visibility all potential interferers, resulting in at most one interference entry per this area (0.004 MES/square mile).
- technical parameters for GLONASS as per Table 2.1.3-1 Signal Path and MES Interference Path
- fuselage blockage of 6 dB and a directivity difference of 3 dB

An en route condition of 10 km aircraft altitude was considered since the Russian Federation based an interference analysis at this altitude. Two conditions are evaluated: one, with the MES directly below the aircraft and the other with the MES at a 45 degree elevation angle to the airborne GLONASS receiver. A link budget is shown in Table 2.1.3-1 for the case of a single MES user and its potential interference into GLONASS for these two conditions. The GLONASS signal path analysis is based upon nominal values from documents IWG2-20 and -27. It was assumed that the elevation angle from the airborne receiver to the satellite would exceed 15 degrees and that this would provide a minimum antenna gain of -2 dB (IWG 2-27, Section 1). The analysis of the MES interference path is based upon elevation angles of 90 and 45 degrees from the MES user to the airborne receiver. Fuselage blockage for these two cases was assumed to be 10 dB directly underneath the aircraft to about 6 dB for the lower elevation angle. The results of the calculations indicate a C/(No+Io) of greater than 30 dB-Hz in both cases which should allow the receiver to maintain signal tracking during testing (per Section 2.1.1 GLONASS Interference Immunity Measurements). The corresponding Eb/(No+Io) is greater than 13 dB which should provide a bit error rate of less than 10^{-6} for the uncoded GLONASS data transmissions.

For an elevation angle of 45 degrees from the MES user to the airborne receiver,